DEVELOPMENT STATUS

AUTOMATION ADVANCED DEVELOPMENT

SPACE STATION FREEDOM ELECTRIC POWER SYSTEM

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ELECTRIC POWER SYSTEM AUTOMATION

The paramount objective for our power system's operation is: to generate and dispatch electric power to the loads while maximizing Space Station Freedom's productivity and without violating any constraints. The initial station operation will use dispatchers aided by human-interactive computational facilities to perform the necessary command and control tasks. These tasks constitute planning and decision-making activities that strive to eliminate unplanned outages. To make quality decisions, the dispatchers must have an acumen sharpened through years of experience. Space Station Freedom will adopt an intensive human command and control approach initially, but we perceive that in the long run there are opportunities to reduce our reliance upon skilled dispatchers and to make faster and more consistent on-line decisions by capturing this knowledge in expert systems. The use of such expert systems is shown in this figure. The gist is to perform a closed-loop command and control function using specialized expert systems to perform diagnosis, security analysis, and overall coordination; and to use conventional algorithms for power scheduling and command generation. To develop and demonstrate our automation design we will use the Lewis Space Station Freedom Electric Power Test-bed.

The command and control cycle begins with a sample of data from the test-bed and from the Operation Management System (OMS). Test-bed data is processed by expert systems that recognize and classify the operating state of the power system and then proceed to perform specialized tasks based upon the results of the classification cycle. Operations Management System requests need no special classification software presently.

The security analysis software assesses the overload risk from possible failure modes that have been identified beforehand. The system is judged secure if there are no contingencies that result in an emergency situation. Aboard our spacecraft, sudden loss of a power converter is an ever present contingency that produces an emergency state. Converter loss will always produce insecure operation and cannot be alleviated without shedding load. Insecure transmission outages, however, may be prevented by reassigning loads to other busses. These insecure operating conditions are translated into constraints upon the scheduling and distribution of power in the system. For source outages, contingency plans for load shedding must be produced; and for transmission outages, rerouting plans must be produced. The plan formulation and selection is performed by specialized software in the Arbiter expert system.

The diagnosis software determines the most likely cause of abnormal operation. Like the security analysis software it generates constraints upon the scheduling and distribution of electric power.

The Arbiter expert system software coordinates the Operations Management System requests, security analysis results, and failure cause diagnosis by specifying appropriate system operating constraints and electrical loads to a scheduling algorithm. The Arbiter software also determines which schedule and operating plan is to be used given the current state of the power system's operation. This current plan is sent to command generation software which provides the interface between the Arbiter expert system and the computers used to operate the test-bed.
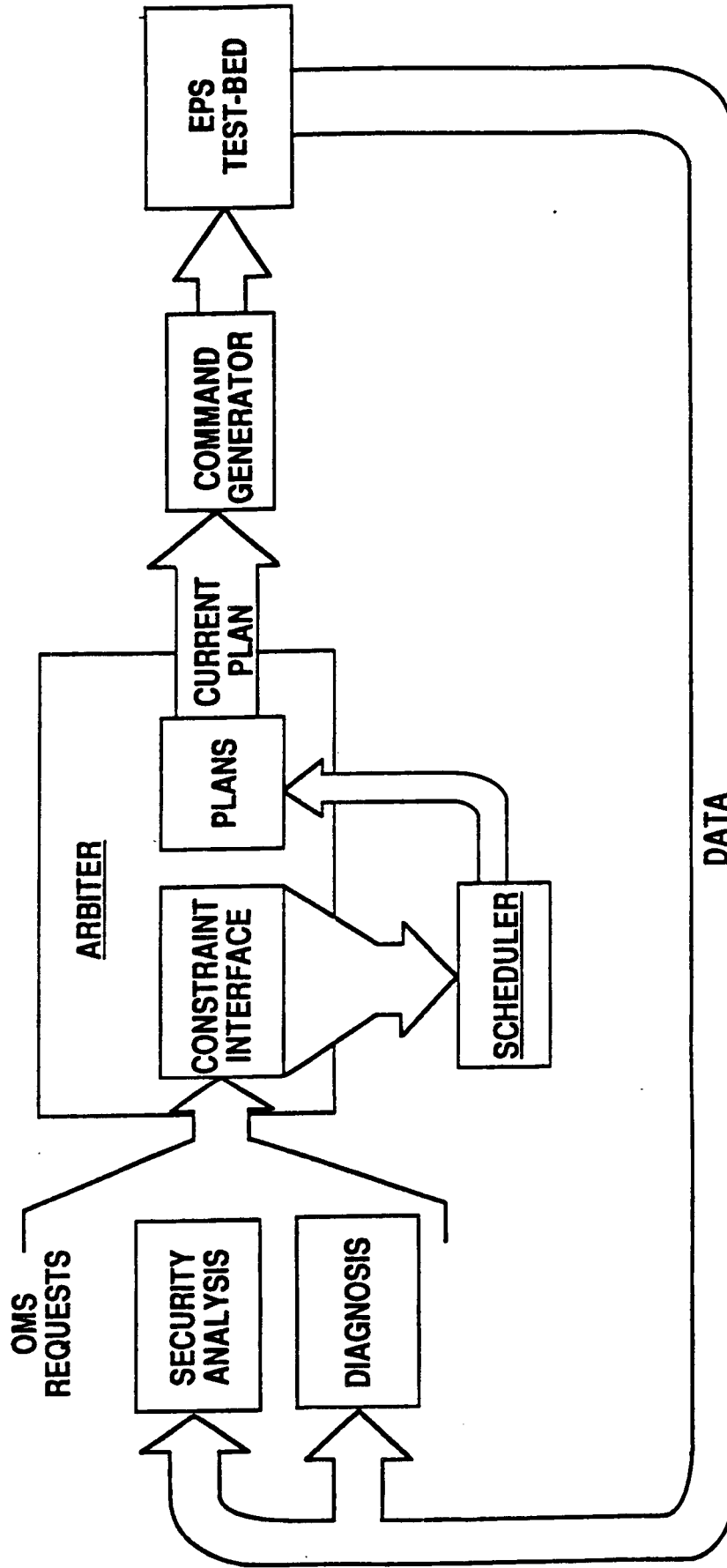
The Scheduler software finds power profiles that maximize productivity and that satisfy the operating constraints stipulated by the Arbiter expert system. The resulting power dispatching schedules repose in memory awaiting selection by the arbitration software.

POWER SYSTEM AUTOMATION

ELECTRIC POWER SYSTEM AUTOMATION

AUTOMATION SOFTWARE FOR DIAGNOSIS

Two expert systems are being developed for the diagnosis function:

The first, APEX, has been developed in KEE for use with 20kHZ switchgear. It is a rule-based expert system that uses antecedent driven logic for generating the failure hypotheses and consequent driven logic for deducing the most likely hypothesis. An explanation facility is used to justify the failure cause analysis. The APEX software can accommodate both static and temporal data. The temporal data is used to identify incipient failures. The incipient detection is based on linear regression and correlation analysis. This algorithm finds "soft" failures by detecting graceful degradation in system performance. Rules are used to isolate the cause of the degradation. The addition of temporal data and detection produces an expert system capable of detecting anomalies such as: insulation breakdown in transformers, contact depletion in mechanical switches, and thermal conductivity degradation in power semiconductors.

The second, TROUBLE III, is being developed in ART for use with the photovoltaic generation and nickel-hydrogen battery storage systems. It is an expert system system that uses set-covering rather than a series of if-then rules to encode the failure knowledge. In this software, a data base linking all known system failures to their known symptoms is built and searched to generate the failure cause hypotheses for observed symptoms. Rules control hypothesis generation and determine the most likely cause. The failure knowledge, however, is stored as data and in easily maintained. TROUBLE III uses a standard reliability analysis tool -- the failure modes and effects analysis -- to produce the symptom and failure data base. Symptoms are detected using rule-based classifiers which process static system measurements.

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POWER SYSTEM AUTOMATION

AUTOMATION SOFTWARE FOR DIAGNOSIS

APEX

- FOR SWITCHGEAR
- RULE-BASED
- KEE
- DETECTION

  STATIC

  TEMPORAL

TROUBLE III

- FOR GENERATION & STORAGE SYSTEMS
- SET-COVERING
- ART
- DETECTION - - STATIC ONLY

AUTOMATED SOFTWARE FOR SCHEDULING

Four algorithms are being investigated to perform the power scheduling functions: three use integer or mixed integer-linear programming and one uses a value-driven algorithm.

The integer programming approach uses the WS Formulation (after its designers Washington and Sheskin) to represent preferences for load time profiles and their starting times. All variables are integers and the decision variables (when to start a load) are limited to values of 0 or 1. A cardinal value system for starting time preferences is maximized subject to operating constraints using an implicit enumeration technique encoded in a program named ZERON.

The mixed integer-linear programs use either the Washington or the DiFilippo formulations to represent loads, the load's usefulness, and the load's starting times. Both formulations use constraint equations with slack variables to apportion available energy among battery storage and loads, and use 0-1 variables to represent the choices. Both formulations use customized versions of a branch and bound search algorithm to maximize a productivity index.

The value-driven resource allocation program uses a free-market economy model in which consumers (loads) bid for available resources and in which trade-offs among conflicting supply alternatives are governed by cardinal measures of value. Unlike the integer and mixed integer-linear programming methods, the value-driven paradigm schedules not only electric power but also all of the other resource providing subsystem aboard Space Station Freedom. The conceptual design of the allocation algorithm is complete and a report is available. A proof of concept simulation is in progress.

AUTOMATION SOFTWARE FOR SCHEDULING

- **INTEGER PROGRAMMING**

  WS FORMULATION

  ZERON SOLVER

- **MIXED INTEGER - LINEAR PROGRAMMING**

  WASHINGTON FORMULATION

  DiFILIPPO FORMULATION

  BRANCH AND BOUND SOLVERS

- **VALUE - DRIVEN RESOURCE ALLOCATION**

  DECISION-SCIENCE APPLICATIONS, INC. FORMULATION

  GENERALIZED LAGRANGE MULTIPLIER SOLVER

AUTOMATION SOFTWARE FOR CONSTRAINT INTERFACES

Constraint interface software in the Arbiter expert system has been developed to convert outputs from constraint generating software into properly formulated scheduling problems. These constraint interfaces are for coordinating the APEX diagnostic expert system with the DiFilippo Formulation scheduler and for coordinating the OMS Request data base with the WS Formulation scheduler. Additional constraint interfaces will be developed as the automation design matures.

POWER SYSTEM AUTOMATION

AUTOMATION SOFTWARE FOR CONSTRAINT INTERFACES

- BETWEEN APEX AND DiFILIPPO SCHEDULER

- BETWEEN OMS REQUEST DATA BASE AND WS SCHEDULER

POWER SYSTEM AUTOMATION

SIMULATION TO SUPPORT AUTOMATION DEVELOPMENT

- POWER GENERATION AND STORAGE

- SWITCHGEAR FAILURE MODES

- INTERACTIVE EXPERIMENT

DEVELOPMENT

Two development paths are being pursued: The first uses the APEX switchgear diagnostic system and the DiFilippo Formulation scheduler to produce load shedding or reconfiguration commands for a small 20kHz test-bed. This test-bed (known as the 20kHz Brass-board) contains several pieces of switchgear and a network of microprocessors for gathering data and commanding the switchgear. The thrust of the development is to integrate expert systems with space power hardware, and to learn how expert systems behave in command and control systems. The second uses simulations to provide the behavior of the power system, its computers, payloads, and other station subsystems. The TROUBLE III diagnostics system, the WS Formulation scheduler, and the OMS request data base are being developed with these simulations.
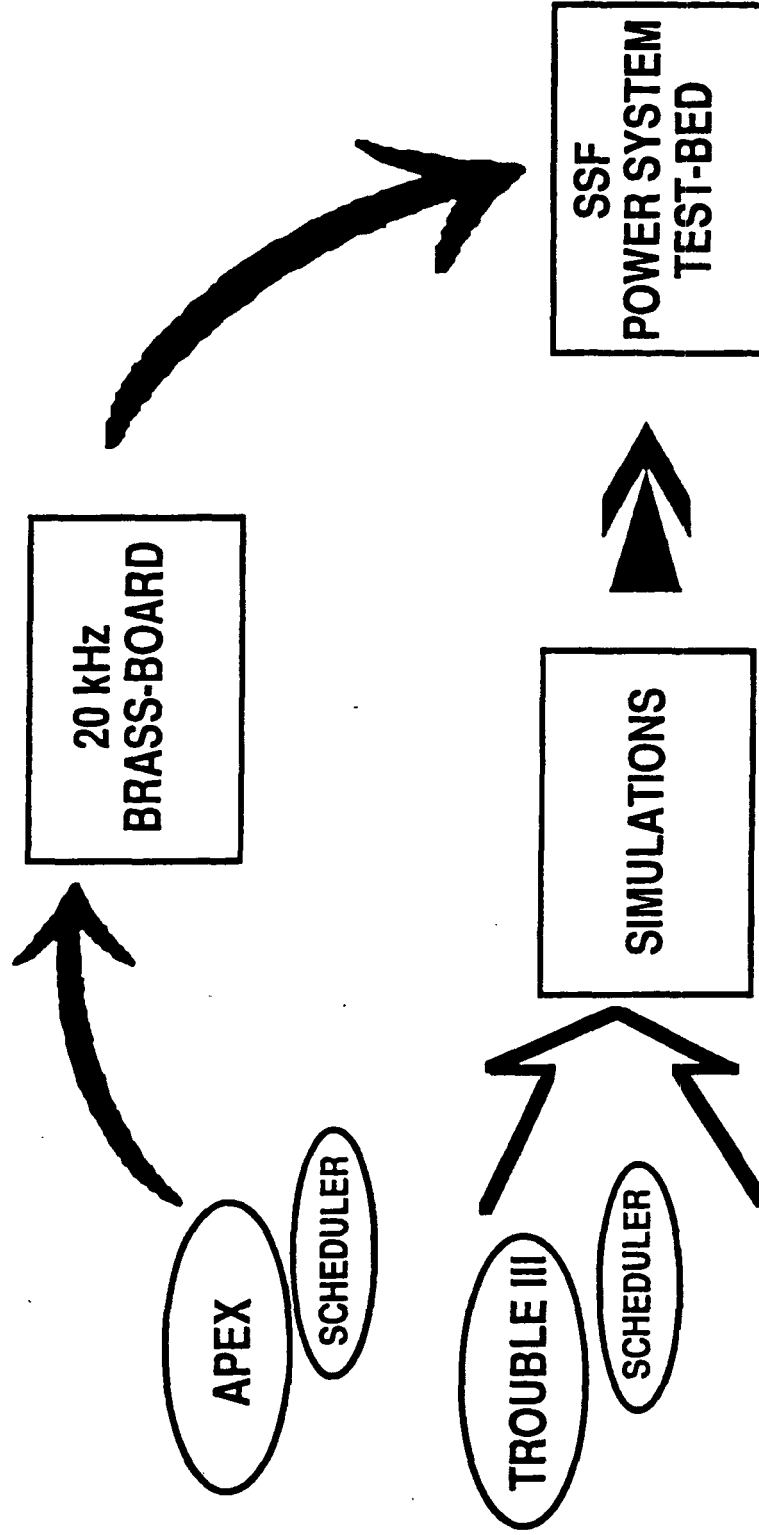
The knowledge gained from the 20kHz Brass-board experiment will be used to guide the automation software development by simulation. The final automation product, a combination of the best performing software, will be evaluated using the Space Station Freedom Power System Test-Bed.

ART/ADA

A development effort is under way to produce Ada versions of the automation software described previously. The objective is to perform a comparative assessment of knowledge-based power system automation developed with LISP-based tools and the same automation developed with an Ada-based implementation of ART. Hardware and software have been procured and personnel from Lewis have been familiarizing themselves with the Ada and ART languages. The first application will be the conversion of the APEX diagnostic system into ART and then into Ada.

POWER SYSTEM AUTOMATION

ART/ADA

- COMPARE LISP AND ADA IMPLEMENTATIONS

- BEGIN WITH APEX

RESPONSIBILITIES

Funding for the automation development is provided by NASA OAST (Code R) and OSS (Code S). The Code R initiatives focus on technology development for: scheduling, diagnostics, cooperative problem solving using multiple expert systems (e.g. blackboard architectures), and human interfaces to expert systems. All of these technologies are applied to general space power systems with particular emphasis on the Space Station Freedom Power System. The Code S initiatives apply specific technologies to the Space Station Freedom Power System, viz., integration of automation products for diagnosis and resource allocation into the Space Station's power test-bed; and seek to identify the hooks and scars required for successful incorporation aboard the Space Station.

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POWER SYSTEM AUTOMATION

RESPONSIBILITIES

CODE R

- APEX DIAGNOSTIC SYSTEM
- SCHEDULING TECHNOLOGY
- DIAGNOSTIC TECHNOLOGY
- CO-OPERATIVE PROBLEM-SOLVING TECHNOLOGY
- HUMAN INTERFACE TECHNOLOGY

CODE S

- TROUBLE DIAGNOSTIC SYSTEM
- VALUE-DRIVEN RESOURCE MANAGEMENT
- TEST-BED INTEGRATION
- ART-ADA
- HOOKS & SCARS IDENTIFICATION